Three paths for achieving sustainable human development: assessing trade-offs

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Abstract

The Sustainable Development Goals (SDGs) set a global agenda for enhancing development to catalyze sustainable societal change. But how achievable are these goals? In this paper we build upon previous research that created three policy pathways for achieving SDG targets: technology, lifestyle change, and decentralized governance. We model these alternative pathways using historically high performing countries as parameter interventions and explore the achievability of nine human development related SDGs to 2050 in an integrated assessment platform. We find that combining the three interventions leads to 63 percent of target values achieved by 2030 and 89 percent by 2050. The most effective individual policy is global technology, and the least effective is reducing individual consumption on improving human development. Achievement in lower secondary education, sanitation, and electricity lag behind other indicators across each of these scenarios. However, even in the most ambitious scenario we do not achieve all SDG indicators. Because our pathway scenarios were created using high performing country development values as our inputs, this suggests that additional policies will be required to achieve sustainable development beyond historical precedence.

1 Introduction

The overwhelming scientific consensus is that the current path of human and environmental development is not sustainable across multiple dimensions. Environmental systems (including air, biota, oceans, water, etc.) are under pressure at both micro and macro levels [1]–[5]. At the same time, billions of people are suffering from the lack of access to basic resources such as clean water, energy and food. In response to these challenges, governments worldwide have formulated a set of 17 sustainable development goals (SDGs) supported by 169 targets, and 232 indicators, together describing a vision for a more sustainable development. The SDGs apply to all countries irrespective of level of development and are an explicitly integrated framework designed to enhance human and natural systems.

In light of these developments, many have explored the achievability of SDG targets across distinct pathways. One area of research has been in the shared socio-economic pathways (SSP) literature [6] which introduces five scenarios related to dimensions of uncertainty associated with climate mitigation and adaptation. This work is focused on framing uncertainty and has led to various studies in areas like climate change [7] and sustainable energy [8], but also in human development systems like conflict [9]. An alternative scenario development approach was used in "Roads to Rio+20", which focused on three alternative policy pathways for achieving SDG targets [10]. This research analyzed the level of intervention required to achieve SDGs across scenario paths representing: Global Technology (GT), Decentralized Solutions (DS) and Consumption Change (CC).

This study fills a gap in the literature by exploring the country level achievability of nine human development indicators measuring SDG achievement across the pathways presented in the Roads to

Rio+20 analysis.[1] Instead of identifying the magnitude of intervention required to achieve different SDGs (the Rio+ example) or creating scenarios that map uncertainty across dimensions (the SSP approach), we create exploratory scenarios using high performing historical development patterns as interventions. Across pathways similar to the Rio+ work, how likely we are to achieve human development related SDGs? If these alternative scenarios do not achieve these targets, where are the gaps? In what regions and across which issue areas do we fall most short of our targets? Are there trade-offs and synergies that can be explored to better understand how patterns of human development unfold across different assumptions? As previous modeling work in this area focuses on environmental goals, are there trade-offs across human and natural systems, for example?

We begin by constructing a Current Path (CP) scenario within the International Futures (IFs) model. This scenario represents a dynamic continuation of policy choices across systems which represents a middle-of-the-road global development path. After building this baseline scenario we construct three alternative scenarios following the Rio+ pathways framework that represent GT, DS, and CC. We add to this a fifth Combined scenario that brings together the interventions across GT, DS, and CC. We explored these five scenarios using the Ifs model for 186 countries for 2030 and 2050. IFs is a dynamically recursive integrated assessment model, with a particular strong representation of human-development related aspects compared to other IAM models.

2 Methods

This paper describes the analysis in the IFs model with respect to human development goals based on the SDGs of a scenario based on current trends (Current Path scenario) and several policy scenarios (DS,

[1] The Rio+ pathways work was "target driven" and normative in the sense that scenarios were created to achieve targets across distinct pathways. This work is "storyline driven" and exploratory in the sense that we draw upon the narratives for pathways described in Rio+ to explore target value achievement across pathways.

GT, and CC scenarios). We specifically look into a set of key indicators. Below, we briefly describe the key methods used.

2.1 International Futures (IFs)

IFs is a long-term integrated assessment model with endogenized sub-models representing agriculture, demographics, economics, energy, environment, governance, infrastructure, international politics, health, and technology (see Figure 1) [11]–[13]. It is a dynamically recursive model with annual time steps to 2100. The IFs system is available for use by others both on-line and in a downloadable version, and it is open source[2].

[2] See the IFs wiki for detailed model assumptions at pardee.du.edu/wiki/International-Futures_(IFs)

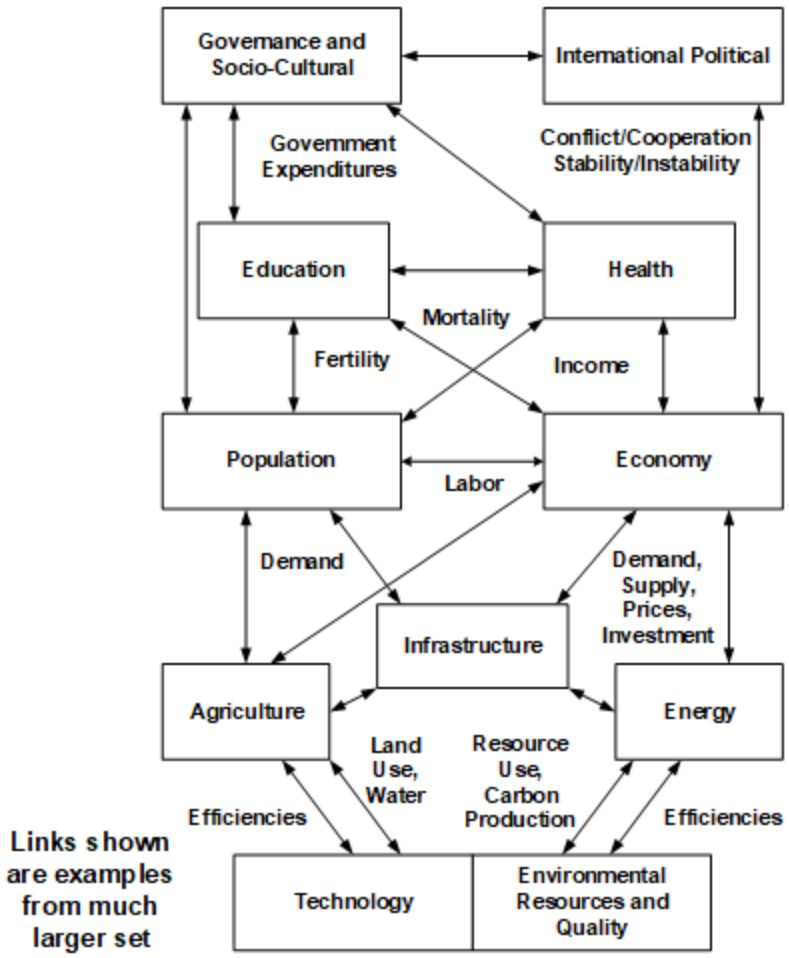

Figure 1: Basic sub-models in IFs

The demographic model uses a standard cohort-component representation [14]. Fertility and mortality are endogenous in response to other drivers, including adult educational attainment and 15 categories of mortality and morbidity from a health model [15]. In the health model, mortality and morbidity are age and sex specific. In the education model students movement through primary, lower secondary, upper secondary, and tertiary levels [16].

The economic model represents capital (across six sectors), labor (by skill), and productivity (with multiple endogenous drivers). As with many models, it calculates equilibrium across supply and demand, though it does not achieve equilibrium at any point in time. Instead, the model uses sectoral

inventory and associated price changes to chase equilibrium across time. The economic model includes a social accounting matrix representing flows across economic sectors (input-output table), and across actors (households, firms, and government) connected to international trade, aid, and FDI flows as well [17].

The partial equilibrium[3] agriculture model differentiates crop, meat and fish, and generates calorie and protein availability [18]. The partial equilibrium energy model differentiates coal, oil, natural gas, hydroelectric power, nuclear power, and renewable energy, tracking resource bases and production [19]. Key variables from the agriculture and energy models, converted to monetary terms, override those of the same sectors in the economic model, while the integration across sectors in the economic model of variables including household, government and firm demand and savings/investment availability provide information to and constraints upon the physical models.

The water model links supply from renewable and nonrenewable sources to demand from agricultural, municipal and industrial sectors. Agricultural water demand is linked to irrigation in the agriculture model and can constrain yields. The infrastructure model represents the extent of and access to paved roads, safe water and sanitation, electricity, and information and communication technologies [20], [21]. It requires investment from public and private sectors that compete with demand from the education and health models, as well as other uses [13].

The physical agriculture and energy models determine land use and generate carbon emissions. A representation based on the MAGICC model [22], [23], used widely in other IAMs, connects carbon emissions to atmospheric CO_2 levels, resultant global warming, and country-level changes in

[3] It is partial in the sense that it is connected only to the physical agricultural system. In the same way the energy sub-module is partial in the sense that it is only connected to the physical energy system. The partial equilibrium physical system modules then connect to the economic module, described previously.

temperature and precipitation. Those feed forward to the agriculture model with a mixture of positive and negative consequences.

Across the broader IFs system, two points of interconnection are especially important. The first is finance, including governmental revenues and expenditures, but also those of households and firms. The economic system is embedded within a social accounting matrix that represents all financial flows within and across these agent categories and assures that representation of those flows is appropriately balanced and constrained—there are no unfunded expenditures [24]. The second area where systems are highly interactive is via the endogenous representation of productivity in the economic model. Multifactor productivity is responsive to changes in human capital (education and health), social capital (including governance security and capacity), physical capital (including infrastructure development and energy prices), and knowledge capital (including research and development spending but also the knowledge transfers through trade).

A broader model of governance represents the state of domestic security or instability, corruption, and inclusion (democracy) and connects to government finance [25]. Socio-political variables also trace changes in basic value/cultural structures, and portray various elements of formal and informal socio-economic structures and processes, including income distribution. The IFs system also represents changes in country material power positions globally, a foundation of international politics [26].

Technological change is important across most of the models in IFs. While exogenously represented in many instances, the production functions in the economic, agriculture, and energy models have elements of learning by doing.

2.2 Scenarios

Scenario analysis often begins with the establishment of a baseline. Baselines are scenarios derived from models that can range from the quite simple to the increasingly complex [27], [28]. Many baseline

scenarios are extrapolations that explicitly assume no new policy. Other baseline scenarios more realistically capture how development is unfolding across time by modeling structural transitions (e.g., changing economic production by sector, or government spending patterns). A more dynamic approach to developing a baseline scenario introduces an increasing number of interacting variables and endogenized relationships. Models with more interacting variables may better illustrate interacting complex systems (and be more realistic) but make it more difficult to interpret results and communicate causality.

2.2.1 The Current Path

Here we use a baseline scenario from the IFs modeling platform called the Current Path (CP). The CP is a baseline that attempts to capture dynamic change across the sectors and countries represented in IFs. The CP has been used in both academic and policy-oriented publications as a forecast scenario that articulates a "most likely" development path [14], [29]–[32].

2.2.2 Modeling Alternative Pathways

To create scenarios that built upon the narratives used in "Roads from Rio+20" pathways we began by evaluating and extending their conceptual logic. For example, DS is a scenario that identifies the impact of focusing on local solutions to global problems. But previous modeling work for this scenario did not fully explain the role that national governments can play in facilitating local solutions. Government is crucial for the achievement of the SDGs in any scenario, but DS requires enhanced governance capacity to achieve the narrative's objectives. See Table 1 for a comparison of Rio+ and IFs scenarios narratives.

Pathway	Rio+20 broad assumptions	IFs broad assumptions
Global Technology (GT)	Achieves the 2050 targets, with a focus on large-scale technologically optimal	Nations make significant investments in technological and international coordination in order to address the major developmental and

	solutions, such as intensive agriculture and a high level of international coordination; for instance, though trade liberalization	environmental issues the world will face during the 21st century. These investments aim to advance an agenda of sustainability by increasing productivity and efficiency particularly in agriculture and low-carbon energy, while increasing international coordination so that these advances can be employed by all.
Decentralized Solutions (DS)	Achieves the 2050 targets, with a focus on decentralized solutions, such as local energy production, agriculture that is interwoven with natural corridors and national policies that regulate equitable access to food	Advances sustainable human development by leveraging local production and distribution channels to significantly extend access to calories, safe water and sanitation, electricity, and health services. These advances benefit from the support of strengthened local governance, and serve to improve energy and agricultural efficiency, reduce loss, and to provide additional sources of income to traditionally peripheral communities.
Consumption Change (CC)	Achieves the 2050 targets, with a focus on changes in human consumption patterns, most notably by limiting meat intake per capita, by ambitious efforts to reduce waste in the agricultural production chain and through the choice of a less energy-intensive lifestyle	An increased awareness of the unsustainability of our current path leads to a significant change in individual consumption patterns in favor of more sustainable food and energy sources, more efficient technologies, a preference for smaller families and more leisure time, an overall reduction in per capita intake, and greater value on conservation.

Table 1: Rio+ Pathways narrative and IFs pathways narrative.

Next, we identified parameters already in IFs that could be altered to model these alternative scenarios. The IFs model is structured with parameters that are used as scenario levers. These parameters can be additive or multiplicative and allow modelers to exogenously impact the behavior of endogenized variables to simulate a policy choice or uncertainty and create an alternative scenario to the CP. We modified parameters within the agriculture, energy, water, and governance modules of IFs (see Appendix A for a complete list of parameters and values assigned in each scenario).

We created exploratory scenarios and not normative scenarios as were created for the Rio+ work. We choose to do this for two reasons. First, we were interested in whether it was possible to achieve human development related SDGs across alternative pathways using high performing historical examples as a benchmark. If we were not able to achieve the SDGs using a hypothetical "best case" scenario, then additional growth in development would be required beyond levels seen historically. Second, a global intervention that achieves human development related SDGs in Chad, for example, requires broadly unrealistic interventions when applied on a global basis.

Identifying plausible, high-performing countries was done by looking at: 1) historically high rates of change across each variable; and 2) the relative position of countries with high rates of change, with respect to broad measures of development (for example, to GDP per capita) across time. We created scenarios that reflected development patterns that were possible (i.e. consistent with what has been observed historically), while remaining ambitious. The magnitude to which we either increased or decreased parameters was in line with historically high performing countries (see the "justification" column in Appendix A).

2.2.3 Evaluation Indicators

The nine SDG indicators explored in this paper are listed in Table 2. These indicators were selected for consistency with earlier work assessing the world's progression towards the SDGs (Moyer, Hedden

under review) and represent a cross-section of the SDGs related to human development. They cover broad aspects of human development (health, education, income). Some are measures of success in top-down policies (government spending on schools, infrastructure) and others are more general outcome indicators of human well-being (poverty, nutrition). These indicators also impact all genders, ages, and ethnicities. The "Variable" column represents the projected indicator in IFs. The "Target Value" column represents the threshold for identifying successful achievement of an indicator.

Goal	Target	Indicator	Variable	Target Value	Historical data source
1: End poverty in all its forms everywhere	1.1: By 2030 eradicate extreme poverty for all people everywhere	1.1.1: Proportion of population below the international poverty line, by sex, age, employment status and geographical location (urban/rural).	% of the population living on less than $1.90 a day at 2011 international prices.	Below 3% of total population.	World Bank, Development Research Group.
2: End hunger, achieve food security, improve nutrition and promote sustainable agriculture	2.1: By 2030 end hunger and ensure access by all people in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round.	2.1.1: Prevalence of undernourishment.	% of population whose food intake is insufficient to meet dietary requirements continuously.	Below 3% of total population.	FAO.
2: End hunger, achieve food security, improve nutrition and promote	2.2: By 2030, end all forms of malnutrition including achieving, by 2025, the internationally agreed the internationally agreed targets on stunting and wasting in children under 5 years of	2.2.1: Prevalence of stunting (height for age <-2 standard deviation from the median of World Health Organization Growth Standards)	% of children under 5 whose weight for age is more than two standard deviations below the median for the	Below 3% of total population.	WHO, Child Growth and Malnutrition.

sustainable agriculture	age, and address the nutritional needs of adolescent girls, pregnant and lactating women, and old people.	among children under 5 years of age, by type (wasting and overweight).	international reference population ages 0-59 months.		
3: Ensure health lives and promote well-being for all at all ages.	3.2: By 2030, end preventable deaths of newborns and children under 5 years of age, with all countries with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1,000 live births and under-5 mortality to at least as low as 25 per 1,000 live births.	3.2.1: Under-five mortality rate.	The probability of a child born in a specific year dying before reaching the age of 5 years, expressed per 1000 live births.	Less than or equal to 25 deaths per 1000 live births.	UN Inter-Agency Group for Child Mortality Estimation.
4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	4.1: By 2030 ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and effective learning outcomes.	4.1.1: Proportion of children and young people: (a) in grades 2/3; (b) at the end of primary; and © at the end of lower secondary achieving at least a minimum proficiency level in (i) reading and (ii) mathematics, by sex.	The number of students successfully completing the last year of primary school in a given year, divided by the number of graduate age.	Greater than 97%.	UNESCO Institute for Statistics (UIS).
4: Ensure inclusive and equitable quality education	4.1: By 2030 ensure that all girls and boys complete free, equitable and quality primary and secondary education leading	4.1.1: Proportion of children and young people: (a) in grades 2/3; (b) at the end of primary; and © at the end	The number of students successfully completing the last year of lower secondary	Greater than 97%	UNESCO Institute for

and promote lifelong learning opportunities for all	to relevant and effective learning outcomes.	of lower secondary achieving at least a minimum proficiency level in (i) reading and (ii) mathematics, by sex.	school in a given year, divided by the number of graduate age.		Statistics (UIS).
6: Ensure availability and sustainable management of water and sanitation for all.	6.1: By 2030 achieve universal and equitable access to safe and affordable drinking water for all.	6.1.1: Proportion of population using safely managed drinking water services.	% of population with access to an 'improved' water source	Greater than 97%	WHO/UNICEF Joint Monitoring Programme.
6: Ensure availability and sustainable management of water and sanitation for all.	6.2: By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls in vulnerable situations.	6.2.1: Proportion of population using safely managed sanitation services, including a hand-washing facility with soap and water.	% of population with access to sanitation services	Greater than 97%	WHO/UNICEF Joint Monitoring Programme.
7: Ensure access to affordable, reliable, and sustainable energy for all	7.1: By 2030 ensure universal access to affordable, reliable, and modern energy services.	7.1.1: Proportion of population with access to electricity.	% of the population with access to electricity	Greater than 97%	World Bank's WDI.

Table 2: SDGs, targets, variables, and data sources evaluated in this paper.

3 Results

In this section we present evidence that 1) even the most ambitious scenario does not achieve the nine indicator target values for all countries by 2050; 2) the GT and DS scenarios are individually the most effective at achieving human development related SDGs; 3) the CC scenario does little to improve development relative to the CP; 4) the Combined intervention improves outcomes broadly, suggesting that these development pathways should be pursued simultaneously; 5) some regions lag behind even in the most ambitious scenarios (sub-Saharan Africa, for example); 6) some indicators are more easily achieved (poverty, for example) than others (lower secondary education completion, for example); 7) some indicators are poorly responsive to different pathways; and 8) a long time-horizon is useful in analyzing the impact of changing pathways on human development.

Figure 2 presents the results for each scenario for selected global indicators. GDP output is highest in the Combined scenario, followed closely by GT and DS while CC and CP track closely. Global hunger is reduced most rapidly in Combined and DS, followed by GT and CC. The share of global population living in poverty reduces most rapidly in Combined and DS in the short run, with GT showing strong improvements in the long run and CC improving poverty relative to CP. Carbon emissions are lower in Combined, and are followed by CC, DS, and GT relative to the CP to 2030. By 2050, however, DS and GT show greater reductions relative to CC or CP.

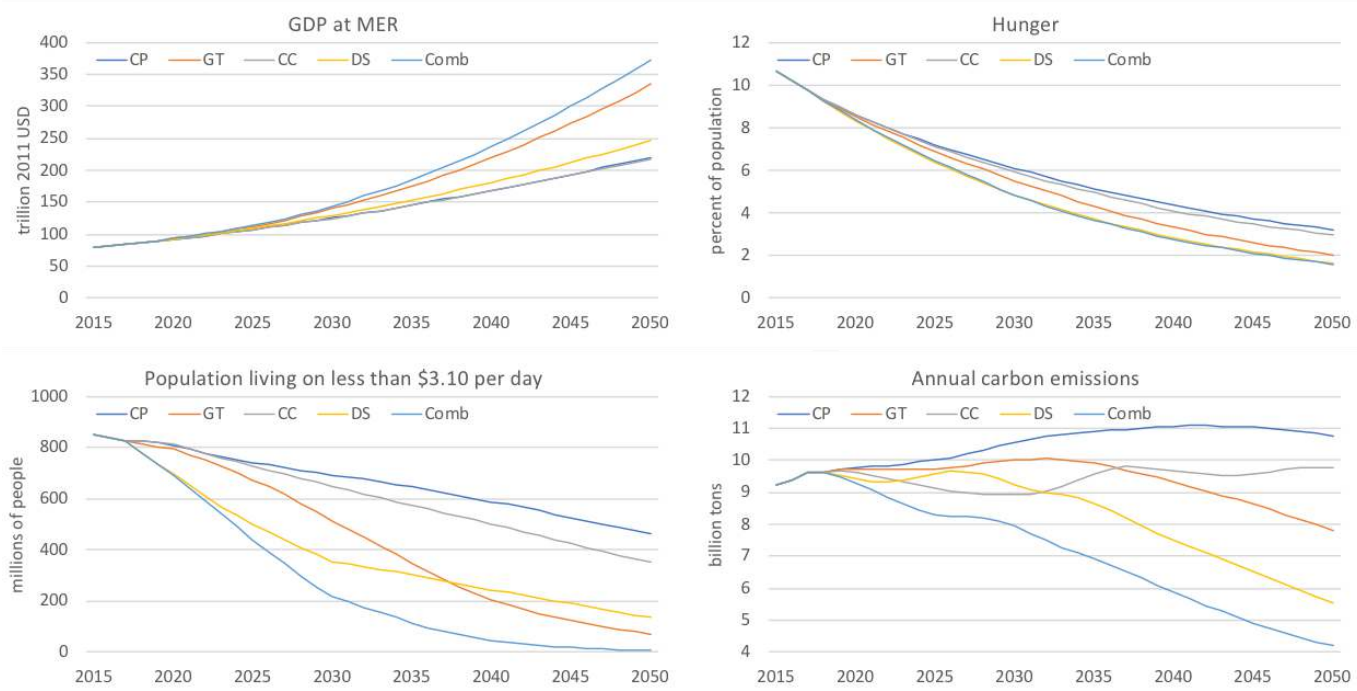

Figure 2: Projections for scenarios across broad out-come indicator

Global results for target value achievement for SDGs are summarized in Table 3. Across the nine human development indicators modeled here for 186 countries, 45 percent of target values were achieved by 2015 (many high-income countries have already achieved many SDGs). Along the CP the number of country-SDGs achieved grows to 53 percent by 2030 and 68 percent by 2050. We find that all three alternative pathways improve the ability for countries to achieve individual SDGs relative to the CP. However, none of the three scenarios provides a sufficient level of change to meet all nine human development related SDG targets in each country by either 2030 or 2050.

Scenario	**2015**	**2030**	**2050**
Current Path	45%	53%	68%
Consumption Change	45%	53%	69%

Decentralized Solutions	45%	59%	78%
Global Technology	45%	58%	84%
Combined	45%	63%	89%

Table 3: Percent of human development related SDGs achieved by scenario in 2015, 2030, and 2050. Red cells indicate lowest value for matrix. Green cells indicate highest value for matrix.

By 2050 each of the alternative scenarios achieves more country-SDGs when compared with the CP. GT leads the way with 84 percent of target values achieved by 2050 followed closely by DS, with 78 percent of target values achieved. These results demonstrate that pathways characterized by more rapid technology diffusion as well as effective governance solving local problems are two development trajectories that improve both environmental outcomes and human development related to our current development trajectory.

The CC scenario reduces individual consumption patterns and is a good pathway for sustainable environmental development (as clearly represented in the Rio+ research) but it significantly underperforms both the DS and GT scenarios on achieving human development. The CC scenario shows only modest improvement relative to the CP by 2050, increasing the number of target values achieved from 68 percent in the CP to 69 percent in the CC. Reducing consumption leads to limited growth in productivity and technological advancement which is responsible for limited progress towards achieving human development related SDGs. This suggests that reduced individual human consumption will have little impact on achieving human development related SDGs beyond a baseline scenario in the medium term.

Though none of these interventions in isolation achieve all of the SDG target values explored in this paper for all countries, combining the interventions across the three scenarios leads to higher levels of country-level SDG target value achievement than any of the three scenarios individually. This suggests

that the different pathways proposed in previous research can be pursued simultaneously to improve human development outcomes. Combining interventions leads to 63 percent of target values achieved by 2030 and 89 percent achieved by 2050, a significant improvement over the CP of development and a broad-based step towards sustainable human development.

While global target value achievement stands at 89 percent in a combined intervention by 2050, in some regions and for some issue areas, development lags significantly behind full target value achievement. In sub-Saharan Africa, for example, undernutrition is projected to persist even in this most ambitious scenario. The lower secondary education attainment indicator target is not achieved in East, Central, North, and Western Africa, Central America, and West Asia, reflecting the long time lags associated with required prior development of primary education. Access to improved sanitation lags behind access to safe water in some areas as well, reflecting a set of historical development preferences whereby access to safe water has been prioritized ahead of sanitation. Finally, access to electricity lags in East and Central Africa, reflecting the challenges of sustainably developing infrastructure systems and the persistent problem of poverty, which is also expected to contain gaps in achievement by 2050.

	CP 2015	CP 2030	CC 2030	DS 2030	GT 2030	Comb 2030	CP 2050	CC 2050	DS 2050	GT 2050	Comb 2050
Extreme Poverty	51%	58%	58%	73%	63%	80%	68%	69%	89%	91%	99%
Hunger	45%	46%	47%	52%	47%	51%	66%	70%	84%	81%	84%
Child Undernutrition	31%	37%	35%	56%	38%	52%	47%	46%	86%	63%	85%
Child Mortality	56%	70%	68%	72%	72%	74%	84%	83%	85%	94%	96%

Primary school completion	61%	71%	73%	73%	78%	79%	85%	90%	90%	98%	99%
Lower secondary school completion	31%	40%	40%	41%	44%	46%	54%	54%	56%	73%	76%
Access to safe water	48%	66%	66%	68%	77%	78%	84%	84%	84%	98%	98%
Access to improved sanitation	27%	36%	36%	36%	46%	46%	55%	56%	58%	85%	83%
Access to electricity	53%	58%	57%	62%	58%	64%	64%	66%	73%	74%	81%

Table 4: Percent of countries achieving target value for nine human development related SDGs by scenario, 2030 and 2050. Red cells indicate lowest value for matrix. Green cells indicate highest value for matrix.

While overall performance across scenarios differs, so does achievement across individual indicators. Some indicators show great potential for improved development. In the Combined scenario, four indicator target values are achieved in over 70 percent of countries by 2030: poverty, child mortality, primary school completion and safe water access.

Other indicators lag behind. For example, nearly half of countries do not achieve the hunger, lower secondary completion, access to sanitation, and underweight children targets even in the most ambitious scenario by 2030. Poor achievement of lower secondary completion targets reflects the structural character of education systems: solving secondary education requires completely filling the primary education pipeline first. Poor performance in sanitation reflects human preference seen in data: humans tend to prefer improving water access before sanitation.

Some indicators show limited growth in target value achievement across scenarios to 2030. The best and worst performing scenarios for child mortality and lower secondary enrollment only differ in the

countries achieving the target value by 6 percentage points (a difference of 11 countries). Greater outcome differentiation occurs across other indicators; poverty shows the largest range in the percent of countries achieving the target value with the Combined scenario improving results by 22 percentage points (41 out of 186 countries) in 2030 relative to the worst performer, CC. This suggests that some human development related SDGs are simply harder to achieve than others with the intervention pathways we have explored here. There is greater variation in our ability to "move the needle" on extreme poverty than there is on other indicators like lower secondary enrollment or child undernutrition.

However, turning to 2050, some of the indicators where progress is limited begin to improve. By 2050, the Combined scenario shows 76 percent of countries complete lower secondary education as opposed to 54 percent in the CC scenario in the same year (up from 46 percent and 40 percent respectively in 2030). This strong divergence in scenario outcomes from 2030 to 2050 suggests that long time horizons are important for understanding how different policy choices may play out in human development systems, even those that appear to be indifferent to interventions over a shorter (15-year) period.

3.1 Exploring results using global population in place of country achievement

Up to this point the analysis has been done at the country level of analysis. But how successful are these scenarios at achieving certain SDGs on a global basis? Does the unit of analysis matter significantly in the assessment of SDG achievement? We argue that it does. Table 5 shows the gap in SDG achievement across development indicator explored here in millions of people and not share of countries who achieve specific target indicator values.

For example, on a global basis by 2030 the Combined scenario projects a world in which 219 million people live in extreme poverty. That represents 2.6 percent of the projected population of 8.4 million people at that time, crossing the target value threshold (see Table 2) for poverty elimination. One could

take this result and conclude that there *is* a plausible pathway to achieving this SDGs that does not require transformational policy change. However, when analyzed on a country basis, 20 percent (37 out of 186) of countries do not achieve the poverty threshold target in this same scenario.

If we took results from our global model and assessed SDG achievement we would come to very different conclusions about achievability compared with assessing results at a country level. A handful of countries are particularly vulnerable to developmental challenges and these individual difference can be smoothed over when using a regional or global level of analysis.[4]

		Poverty	**Hunger**	**Child Undernut.**	**Child Mort.**	**Primary Ed.**	**Secondary Ed.**	**Electricity Access**	**Sanitation**	**Water**
		million people	*million people*	*million children*	*million children*	*million children*	*million children*	*million people*	*million people*	*million people*
2015	**CP**	**851**	**786**	**102**	**5.7**	**94.8**	**259**	**862**	**2,353**	**2,680**
2030	**CP**	**693**	**519**	**65**	**4.1**	**51.9**	**215**	**680**	**1,397**	**1,952**
	GT	512	470	57	3.4	43.1	203	572	1,026	1,553
	CC	650	500	54	3.3	49.3	211	643	1,354	1,903
	DS	355	413	37	3.4	50.7	213	471	1,343	1,893
	Comb	219	409	33	2.5	41.2	200	394	1,029	1,530
2050	**CP**	**462**	**312**	**36**	**2.5**	**25.6**	**159**	**460**	**885**	**1,146**
	GT	70	197	23	1.3	5.3	110	179	196	376
	CC	350	277	28	1.8	17.9	132	355	743	974
	DS	134	160	16	2.0	21.9	149	248	777	983

[4] For example, while southern Africa as a whole achieves a 98 percent access to safe water by 2050, 9 of the 19 countries in the region to not achieve this target in the most optimistic scenario.

	Comb	6	149	13	0.9	3.1	89	85	241	364

Table 5: Gap analysis: how big is the problem that remains? Red cells indicate lowest value for each column. Green cells indicate highest value for each column.

3.2 Trade-offs and synergies

As noted earlier, the SDGs are an integrated development framework across human and natural systems. As such, pursing one policy can help or hurt the pursuit of other policies. One example of this is that the pursuit of hunger alleviation by increasing land under cultivation can reduce biodiversity, improving one SDG and harming another. Because of this, the study of policy synergies and trade-offs has become an increasingly important research topic [33].

Trade-offs may occur due to finite physical resources; for instance, food and biofuel crops may compete for land and/or water, resulting in a trade-off between targets in SDG 2 (zero hunger) and 7 (affordable and clean energy) [34]. Somewhat counter-intuitively, trade-offs may even exist within goals; for instance, Schmidt, Gostin, and Emanuel [35] argue that pursuing target 3.8 (universal health coverage) could actually undermine targets focused on public health outcomes. Finally, trade-offs may result not from competing objectives but from the scarcity of financial resources, whereby directing funds in one area makes them unavailable for use in another.

Research quantifying trade-offs and synergies across SDGs has been limited. Some approaches involve in-depth analysis or quantitative modeling of trade-offs limited to a small number of goals or targets in one area [36], [37]. Most studies of in this area rely on qualitative assessments of trade-offs that are then quantitatively [38]–[40].

In this section, trade-offs and synergies are each defined in two ways. First, pursuing an indicator can cause trade-offs if it reduces the ability of countries to pursue other SDG targets. Interventions aimed at achieving one goal that undermine the ability to pursue a different goal are referred to as having high

pursuit trade-offs (this might result from the use of constrained financial resources) Second, a goal or a specific indicator for a goal can actually be harder to achieve when other goals are being targeted (some poverty reduction could increase environmental damage). Goals or specific indicators that become more difficult to achieve when other SDGs are approached are referred to as being *trade-off vulnerable*.

In the evaluation of SDG priorities and policies, the opposite of a trade-off is a synergy. When an SDG indicator is improved with directed policy leading to enhanced achievement of other targets, that intervention can be described as having high *pursuit synergies* (spending on water and sanitation might help improve nutrition and reduce child mortality) Additionally, if achievement of a goal tends to become easier as other goals are approached or achieved, that goal is referred to as being *synergy receptive* (broadened participation in education could facilitate poverty reduction)

We created nine additional scenarios that each pursued a specific SDG target indicator in this paper (Appendix B). Table 6 summarizes the results from this exercise and compares results against CP. This table explores the impact of sectoral investment (columns) on the number of countries that achieve the nine SDGs explored in this paper (cells) across development indicator (rows) relative to the Base Case in 2030. The values in cells represent the number of countries (out of 186) that see improvement (green), no significant change (yellow), or a decline (red) in the value of the projected row indicator.

For example, the Cash Transfers column represents an increase in cash transfers to the poorest in society. The impact of this intervention is that 142 countries are projected to significantly reduce their extreme poverty levels, 44 countries are forecast to see no significant change, and 0 countries are forecast to increase extreme poverty. While this single intervention is positive for the alleviation of extreme poverty, it produces mixed results across the other indicator categories. This is because cash

transfers draw upon other resources and make it more difficult to invest in reducing child mortality, enrolling students in education, and improving infrastructure.

Table 6: Quantifying trade-offs and synergies: Rows represent nine human development related SDGs explored in this paper. Columns represent scenario interventions around the Current Path. Values in cells represent the number of countries (out of 186) that see improvement (green) improvement (green), no significant change (yellow), or a decline (red) in the value of the projected row indicator.

	Cash transfers to unskilled households			Increased caloric demand and access			Reduction in child undernutrition			Reduction in child mortality			Increased primary school throughput			Increased secondary school throughput			Increased access to piped water			Increased household plumbing			Increased indoor electrification		
Poverty	142	44	0	111	45	30	46	79	61	83	71	32	64	101	21	76	84	26	122	59	5	113	64	9	66	99	21
Hunger	184	2	0	182	0	4	86	87	13	126	51	9	41	145	0	52	132	2	113	66	7	111	71	4	53	122	11
Child Undernut.	59	32	95	180	0	6	186	0	0	83	89	14	6	146	34	18	124	44	129	55	2	132	54	0	26	121	39
Child Mort.	76	22	88	167	0	19	186	0	0	186	0	0	25	132	29	72	63	51	137	49	0	131	55	0	69	111	6
Primary Ed.	19	139	28	9	110	67	3	155	28	26	150	10	115	70	1	55	64	67	46	139	1	48	138	0	14	151	21
Secondary Ed.	28	77	81	12	66	108	7	133	46	92	92	2	33	84	69	186	0	0	76	108	2	70	111	5	21	133	32
Water	36	27	123	24	75	87	1	125	60	45	119	22	8	152	26	4	122	60	176	10	0	59	112	15	20	124	42
Sanitation	47	29	110	19	95	72	0	131	55	38	133	15	6	152	28	11	129	46	50	123	13	163	23	0	18	129	39
Electricity Access	68	36	82	28	113	45	6	142	38	56	129	1	33	151	2	16	157	13	59	127	0	59	125	2	97	88	0

Of the target indicators explored here, the variables with the greatest *pursuit synergies* are spending on access to water and sanitation. Investments here produces near-term virtuous cycles that directly improve economic productivity by making workers more productive but also improve longer-term productivity by reducing stunting and other health issues. They enhance government revenue by increasing economic growth and make people healthier.

The interventions with the highest *pursuit tradeoffs* in this modeling exercise are increasing cash transfers, subsidizing caloric demand, and reducing childhood undernutrition. These interventions reallocate resources from other sectors and have a more limited impact on improving development indicators across sectors as compared with increasing access to water and sanitation.[5]

Education completion (both primary and secondary) along with access to water, sanitation, and electricity are the most *trade-off vulnerable*. These indicators require government investment and

[5] It is important to note that it is possible to pursue achieving SDGs using alternative policies to those modeled here. That would create different trade-offs and synergies than those represented here.

targeted investments to improve achievement in other variables draws down resources without increasing economic growth enough to off-set these reductions. The SDG indicators that are most *synergy receptive* are poverty, hunger, child undernutrition, and child mortality. Each of these SDG indicators represents a lack of access to basic human inputs for the most vulnerable populations. In contrast to indicators that are more driven by government intervention, these indicators may be more responsive to spill-overs from other sectors through marginal improvement driven by investment elsewhere.

4 Conclusions

The SDGs are a global agreement to put the course of human development on a sustainable pathwe4thj. In this paper we have implemented the three "Roads from Rio+20" pathways within the IFs model to evaluate their impact on achieving target values for human development related SDGs. We found that each of these pathways can improve the course of human development relative to the baseline trajectory. In both the DS and GT scenarios, sustainable human development pushes forward much faster than the CP. Pursuing development strategies that attempt to harness technology and effective local governance for development should be priorities for any SDG achievement agenda.

The CC scenario did not significantly improve these human development SDG indicators relative to the CP by 2030, and only modestly improves outcomes by 2050. While this scenario does very well in improving environmental related outcomes, it simply does not produce the economic growth needed to draw hundreds of millions of people out of poverty. While the CC scenario in isolation does not produce enough to solve global extreme poverty, the Combined Scenario shows that individual consumption reduction in conjunction with other policies that promote technology and good governance can produce synergies that broadly enhance development while also being sensitive to environmental systems.

When aggregating the national results to the global level on a population basis, it appears that we are not very far from achieving many SDGs, especially if we properly prioritize development strategies. The combined intervention scenario, for example, achieves an extreme poverty target value threshold (as a share of the projected global population) of less than 3 percent by 2030. However, when measuring the same target (less than 3 percent in extreme poverty) at the country level, only 80 percent of countries achieve it and 37 fall short of the goal. The unit of analysis matters significantly in the assessment of development target achievement.

Modeling development at the country unit of analysis also highlights synergies and trade-offs that require further investigation and understanding. Some development objectives are difficult to achieve in the near or medium term because they require prior development achievement. For example, lower secondary education completion requires a country to have a primary education pipeline that is filled with students ready to graduate. Targets on other development indicators are more challenging to achieve because they are driven by persistent problems driven by conflict and poor governance that are not fully addressed in these pathways and remain challenges globally.

This modelling effort demonstrates that if interventions are constrained using historically high performing countries as benchmarks (see Appendix A), then none of these pathways can achieve the human development related SDGs in all countries by 2030 or 2050. If the international community remains committed to achieving these goals, transformational policymaking is required. When assessed on a country basis, some can achieve the SDGs using historically high performing countries as benchmark examples in scaling policy interventions. But the country level analysis also highlights a problem with achieving SDGs in some of the most vulnerable countries. This group of states should be the focus of development assistance and must be the focal point of transformational policies meant to improve the human condition.

The character of this transformation is yet to be determined, but this research shows the importance of using integrated assessment tools with more attention to human development, and model disaggregation to the national level to better understand how different systems interact and unfold. Integrated assessment models allow for better informed decisions that empower countries, civil society, and international organizations to coordinate strategies to more effectively set and pursue development goals.

Appendix A: Pathways assumptions added to IFs

This table reviews the parameters that were impacted in IFs, the description related to the scenario narrative, the magnitude of intervention (comparing that with the CP), and a justification for the magnitude of the intervention based on evidence.

Scenario Name	Description of Intervention	Outcome Indicator	Unit of Measure	Geography	2017 Value	Scenario 2030 Value	CP 2030 Value	Justification
Global Technology	Agricultural productivity increases	Yield in agriculture	tons per hectare	World	6.3	9.4	7.1	WB income groups (excluding high-income) grow at historical rate as opposed to slowing.
		Yield in agriculture	tons per hectare	High-Income Economies	4.8	8.1	5.3	Assumes technology is applied to a greater extent (or first) in high-income economies.
	Advances in low-carbon energy production technologies reduce the cost of nuclear, hydro, and other renewable energy sources	Hydro energy production	bil BOE	World	2.8	5.3	4.0	Growth in line with high country performance historically.
		Nuclear energy production	bil BOE	World	4.9	8.4	4.8	Growth in line with high country performance historically.
		Other renewable energy production	bil BOE	World	2.5	15.6	8.7	Growth in line with high country performance historically.
	Increased public and private investment in	Research and development	percent of GDP	World	2.0	2.6	2.0	Many countries have experienced increases of this magnitude. Finland

	research and development	spending portion of GDP						grew from 1.97 in 1990 to 3.44 in 2003.
		Government expenditures by destination sector	percent of GDP	World	0.3	0.6	0.3	(R&D) Finland increased R&D spending from 0.29 in 1981 to 0.49 in 1993. France, Iceland, and New Zealand have all spent above 0.6 percent of GDP on R&D at some point in time.
	Greater demand for science and engineering graduates	Education, tertiary, graduation share, science and engineering	percent of graduates	World	20.2	31.5	21.3	Iran and Portugal have increased science and engineering tertiary share of graduates by more than 10 percentage points, in less than 13 years.
		Education, tertiary, graduation rate	percent of of-age group	World	26.2	56.0	39.9	Belarus increased tertiary graduation rates from 24.5 in 2000 to 63.6 in 2013.
	Greater trade liberalization (particularly in agricultural and energy sectors where prices become particularly competitive)	iMports	percent of GDP	World	29.7	36.9	29.9	Cuts protectionism in half. Imports as a percent of GDP grow at a similar pace to post-Cold War era.

	Greater foreign aid (comprised of fewer loans)	Aid (foreign), net	percent of GDP	OECD	0.23	0.99	0.22	Norway, Sweden, and Luxembourg have all made foreign aid donations of 1% of GDP or greater at some point in time, but this is high. Non-OECD inflows reach mid 1990s levels
	Liberal migration policies	Migration rate(inward), net computed, percent of population	percent of population	High-Income Economies	0.2	0.4	0.2	Reaches net inward migration levels seen in the mid-2000s.
	An increase in foreign direct investment	FDI (foreign direct investment) annual inflows	percent of GDP	World	3.3	5.2	3.6	Similar to smoothed growth rate between 1995 and 2010.
	The introduction of a progressive carbon tax	Energy demand	bil BOE	OECD	36.4	39.3	38.1	From Sustainability First scenario for UNEP GEO4.
		Energy demand	bil BOE	non-OECD	54.3	78.5	75.3	From Sustainability First scenario for UNEP GEO4.
Consumption Change	An overall reduction in energy demand	Energy demand	bil BOE	World	90.7	92.1	113.4	Holds demand relatively constant (instead of increasing)
	Significant reductions in meat consumption (offset	Calories per capita available	per capita per day	World	485.3	273.0	541.8	(meat) Multiple countries have seen a decrease in meat consumption, though no developed country has

	by an increase in calories from crops)							seen a decrease to this magnitude
		Calories per capita available	per capita per day	World	2,408	2,801	2,528	(crops) This just makes up for the foregone meat calories
	Reduction in food waste	Waste of food by consumer	percent of demand	World	2.8	2.5	3.0	Brings the world in line with where we initialize Brazil (which happens to be the least wasteful country according to IFs)
	Greater conservation of water by individuals, farms, and industry alike	Water Demand by sector: Municipal, Industrial, Agriculture	cubic kilometers	World	4,044	2,631	4,319	Water demand remains constant instead of increasing.
	Parents elect to have fewer children	Total fertility rate (births per woman over lifetime)	births per woman	World	2.5	2.0	2.3	Low-income economy TFR reduces at a similar (but slower) pace to Tunisia during the mid to late 1980s.
Decentralized Solutions	Increase renewable energy and hydropower production	Hydro energy production	bil BOE	World	2.8	5.4	4.0	Similar to Indonesia, Iceland, Nigeria, and Panama during the 1990s and 2000s.
		Other renewable energy production	bil BOE	World	2.5	20.8	8.7	5-year moving average growth rates peak at 23 percent (Base Case peaks at 11 percent). This has been achieved by multiple countries

								(Australia, Austria, Russia, India…)
	Improve energy efficiency	Energy, electricity, transmission and distribution loss as a percentage of total production	percent of production	World	7.9	4.2	6.6	Iceland reduced food loss from 7.9 to 4.2 percent loss in 9 years.
	Higher agricultural yields	Yield in agriculture	tons per hectare	High-Income Economies	4.8	6.9	5.3	Grows roughly at historical rate instead of slowing.
		Yield in agriculture	tons per hectare	Up. Mid. Income Economies	8.5	13.1	9.6	Grows roughly at historical rate instead of slowing.
		Yield in agriculture	tons per hectare	Low. Mid. Income Economies	6.0	9.2	6.9	Similar to what Up. Mid. Income Economies did from 2000 to 2013
		Yield in agriculture	tons per hectare	Low-Income Economies	2.6	5.4	3.0	Similar to Thailand's yield gains during the 1970s and 1980s.
	Additional sources of revenue for participating communities	Domestic GINI index of inequality (larger is more unequal, from 0 to 1)	index	World	0.39	0.30	0.40	Less of a rate of reduction than Brazil during the 2000s. This, however is meant to simulate the decentralization of production as opposed to

								transfers (which appears later).
	Increased land under cultivation	Land	mil hectares	World	1,590	1,751	1,626	Between 1995 and 2008, Low-Income Economy crop land expanded by roughly 12 percent
	Increased access to quality calories	Malnourished children (under 5) as percent	percent of children	World	14.5	5.6	9.8	Mexico reduced child undernutrition from 14.8 in 1996 to 3.4 in 2006, though some of this should be attributed to improvements in water and sanitation access.
		Malnourished population as percent	percent of population	World	9.7	4.9	6.1	Multiple countries have seen similar improvements to this intervention.
	An increase in access to electricity and modern cook stoves	Cook Stoves	percent of households	World	68.4	84.3	81.8	Intervention from Kuhn et al. (2016).
	A reduction in agricultural transportation loss	Agricultural loss between farm and table	percent of production	World	5.3	2.2	5.1	Reducing food loss by more than half unreasonable.
	Strengthen governance participation and efficiency	Democracy, Polity index (Range: 0-20; higher is better)	index (0 to 20)	World	13.5	15.7	14.3	Intervention is similar in magnitude to governance effectiveness.
		Government effectiveness	index (0 to 5)	World	2.5	3.5	2.7	Georgia had a similar (larger, though starting

		(quality), factor score; higher is better						at a lower level) increase during the Rose Revolution. Croatia increased from 2.6 in 1998 to 3.2 in 2012 (0.6 over 14 years).
	Higher demand for vocational education	Education, Lower Secondary, vocational as % of enrollment in all programs	percent of lower-secondary enrollment	World	1.3	21.4	1.4	Netherlands increased lower secondary vocational share from 4.5 in 1999 to 29.3 in 2012.
		Education, Upper Secondary, vocational as % of enrollment in all programs	percent of upper-secondary enrollment	World	22.3	40.7	21.6	Portugal increased upper secondary vocational share from 24.1 in 2000 to 45.8 in 2013. Other countries have increased upper second vocational shares by a greater amount over a similar period.
	Governments provide an increased access to capital and insurance coverage to unskilled households	Government to household transfers, welfare (all non-pension transfers)	percent of GDP	World	5.5	7.2	4.8	Increasing transfers as a share of GDP by more than 30 percent unreasonable.
		Government to household transfers, welfare (all	percent of GDP	Low-Income Economies	1.7	3.4	1.6	More than doubling transfers as a share of GDP unreasonable.

		non-pension transfers)						

5 Appendix B: Modeling assumptions used to evaluate potential synergies and trade-offs

Scenarios were constructed to evaluate synergies and trade-offs. The aim of the exercise was to explore how aggressive interventions into specific issue areas impacted the achievement of SDGs across other issue areas.

Scenario	Parameter	Definition	Geography	2018	2030	Notes
Poverty	govhhtrnwelm	Government to household welfare (all non-pension) transfers, multiplier	World	1	4	Transfers to unskilled households
Hunger	malelimprecisesw	Switch to turn on (1=on) elimination of hunger only for undernourished pop	World	1	1	Focusing intervention
	malnelimstartyr	Begin year for an elimination of hunger scenario - works with malnelimtargetyr	World	2018	2018	Intervention year
	malnelimtargetyr	Target year for an elimination of hunger scenario - works with malnelimstartyr	World	2019	2019	Short horizon chosen to offset endogenous push-back
	clpcm	Per capita calorie demand multiplier	World	1	1.5	50 percent increase in caloric demand
	gdsm	Government expenditures by destination multiplier	Country	Varies	Varies	Spending estimated on a per-country basis

	malnm	Malnutrition, multiplier	World	1	0.01	Specifically child malnutrition
	malelimprecisesw	Switch to turn on (1=on) elimination of hunger only for undernourished pop	World	1	1	Focusing intervention
Child Undernut.	gdsm	Government expenditures by destination multiplier	Country	Varies	Varies	Spending estimated on a per-country basis
	hlmortcdchldm	Comm. Dis. Mortality Multiplier for Children under 5	World	1	0	Eliminate child deaths from communicable disease
Child Mort.	gdsm	Government expenditures by destination multiplier	Country	Varies	Varies	Spending estimated on a per-country basis
	edpriintntrgtyr	Education, Primary, Net Intake Rate, Target Year (number of years from base year to reach 100%)	World	15	15	Targeting 100 percent intake in 15 years
	edprisurtrgtyr	Education, Primary, Survival Rate, Target Year (number of years from base year to reach 100%)	World	15	15	Targeting 100 percent survival in 15 years
Primary Ed.	edseclowrtrantrgtyr	Education, Sec Lower, Transition Rate, Target Year (number of years from base year to reach 100%)	World	15	15	Targeting 100 percent transition in 15 years

	edpriintntrgtyr	Education, Primary, Net Intake Rate, Target Year (number of years from base year to reach 100%)	World	6	6	Requires significant primary push to achieve secondary gains
	edseclowrtrantrgtyr	Education, Sec Lower, Transition Rate, Target Year (number of years from base year to reach 100%)	World	12	12	Requires significant primary push to achieve secondary gains
	edsecupprtrantrgtyr	Education, Sec Upper, Transition Rate, Target Year (number of years from base year to reach 100%)	World	12	12	Targeting 100 percent transition in 15 years
	edseclowrgram	Education, Lower Secondary, Graduation rate, multiplier base 1	World	1	3	Two parameters to offset endogenous push-back
Secondary Ed.	edseclowrgradgr	Education, lower secondary, general, Graduation rate, annual growth parameter	World	5	5	Two parameters to offset endogenous push-back
Water	watsafem	Water source safe, percentage of people with access to, multiplier	World	1	10	Access to piped water
Sanitation	sanitationm	Sanitation, improved, percent of population with access to, multiplier	World	1	10	Access to improved sanitation
Electricity	infraelecaccm	Electricity access, multiplier	World	1	3	Urban and rural combined (total)

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